MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2022/2023 (TERM ID 2220)

ENT3036 SEMICONDUCTOR DEVICES

(NE)

4 JULY 2023
9:00 A.M - 11:00 A.M.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This question paper consists of 7 pages including cover page with FOUR questions.
2. Attempt **ALL** questions and the distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

Question 1

a) An abrupt pn junction with zero bias has dopant concentrations of $N_a = 1 \times 10^{17}$ cm^{-3} and $N_d = 5 \times 10^{15}$ cm^{-3} at T = 300 K. Calculate

i) the Fermi level on the n side of the junction with respect to the intrinsic Fermi level. [3 marks]

ii) the Fermi level on the p side of the junction with respect to the intrinsic Fermi level. [3 marks]

iii) build in voltage, V_{bi}. [3 marks]

iv) space charge width in the n-type region, x_n.. [4 marks]

v) space charge width in the p-type region, x_p. [4 marks]

vi) peak electric field, E. [3 marks]

b) The following currents are measured in a uniformly doped npn bipolar transistor:

$I_{nE} = 1.20$ mA $I_{PE} = 0.10$ mA

$I_{nC} = 1.18$ mA $I_R = 0.20$ mA

$I_G = 0.001$ mA $I_{pc0} = 0.001$ mA

Determine

i) α [1 mark]

ii) γ [1 mark]

iii) α_T [1 mark]

iv) δ [1 mark]

v) β [1 mark]

Question 2

a) A silicon p-channel pn JFET at 300 K with gate doping concentration of $N_a = 2 \times 10^{16}$ cm^{-3}, $N_d = 10^{18}$ cm^{-3}. Determine channel thickness, a, to achieve pinch-off voltage of $V_p = 2.25$ V. [6 marks]

b) An n-channel single-gate silicon JFET at T = 300 K with impurity doping concentrations of $N_D = 4 \times 10^{16}$ cm^{-3} and $N_A = 5 \times 10^{18}$ cm^{-3}. The channel thickness dimension is a = 0.35 μm. Calculate:

i) The internal pinch-off voltage V_{p0}. [3 marks]

ii) V_{bi}. [3 marks]

iii) the pinch-off voltage V_p. [1 mark]

iv) Determine the undepleted channel thickness at the drain terminal for

I) $V_{GS} = 0$, $V_{DS} = 1$ V [4 marks]

II) $V_{GS} = -1.0$ V, $V_{DS} = 1$ V [4 marks]

III) $V_{GS} = -1.0$ V, $V_{DS} = 2$ V [4 marks]

Continued.....

Question 3

(a) A metal-oxide-semiconductor (MOS) capacitor consisting of a metal gate, a silicon dioxide (SiO_2) layer, and a *p*-type silicon substrate.

(i) Describe the accumulation mode of holes and sketch the corresponding band diagram through the whole MOS capacitor.

[3+4=7 marks]

(ii) Describe the inversion mode of electrons and sketch the corresponding band diagram through the whole MOS capacitor.

[3+4=7 marks]

Label clearly the metal layer, SiO_2 layer, *p*-type silicon substrate, conduction band E_c, valence band E_v, intrinsic Fermi level E_{Fi} and Fermi level E_F on both diagrams.

(b) The intrinsic concentration of Silicon is $n_i = 1.5 \times 10^{10}$ cm^{-3} and the relative permittivity of Silicon is 11.7.

(i) Calculate the *maximum space charge width* x_{dT} of a *p*-type silicon MOS capacitor with acceptor doping concentrations of $N_a = 5 \times 10^{15}$ cm^{-3} and $N_a = 5 \times 10^{16}$ cm^{-3} at $T = 300$ K.

[4+4=8 marks]

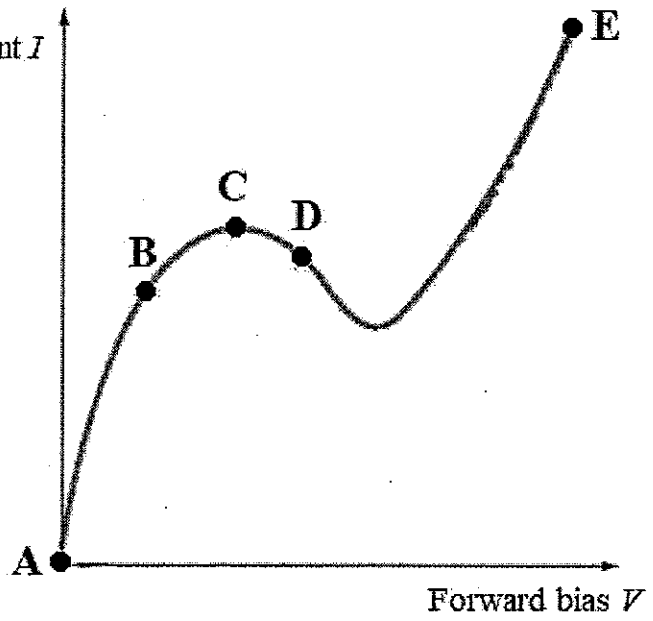
(ii) Based on the results obtained from **Q3(b)(i)**, describe the relationship between the maximum space charge width with the acceptor doping concentration.

[3 marks]

Continued.....

Question 4

(a) With five suitable energy band diagrams, explain the operations of A, B, C, D, and E of a tunnelling diode that can produce the forward-bias current-voltage characteristic as shown in Fig. **Q4(a)**.



[5×3=15 marks]

(b) An p^+-n-i-n^+ Impact Ionisation Avalanche Transit-Time (IMPATT) diode can be used as a high-frequency microwave electronics device.

(i) Draw and label the main device structure of an IMPATT diode.
[4 marks]

(ii) Describe how impact ionisation happens in the IMPATT diode.
[3 marks]

(iii) Calculate the operating frequency of the IMPATT diode if the saturation velocity of the hole is 1.5×10^6 cms^{-1} and the drift region length is 2 μm.
[3 marks]

End of Paper

LIST OF CONSTANTS:-

Electronic charge	e	1.602×10^{-19} C
Planck's constant	h	6.626×10^{-34} Js
Speed of light	c	3×10^{8} ms^{-1}
Temperature [K]	$T = (T\,[°C] + 273)$ K	
Boltzmann constant	k_B	1.381×10^{-23} JK^{-1}
		8.6173×10^{-5} eV/K
Electron mass	m_0	9.11×10^{-31} kg
Permittivity of free space	ε_0	8.854×10^{-12} Fm^{-1}
		8.854×10^{-14} Fm^{-1}
Dielectric constant of Silicon at 300 K	ε_r	11.7
Dielectric constant of Silicon oxide at 300 K	ε_r	3.9
Dielectric constant of Gallium Arsenide at 300 K	ε_r	13.1
Thermal voltage	V_t	0.0259 V
Intrinsic concentration of Silicon at 300 K	n_i	1.5×10^{10} cm^{-3}
Intrinsic concentration of Silicon at 373 K	n_i	2.5×10^{12} cm^{-3}
Intrinsic concentration of Gallium Arsenide at 300 K	n_i	1.8×10^{6} cm^{-3}

Formulae

$$V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

$$E_F - E_{Fi} = kT \ln\left(\frac{N_d}{n_i}\right)$$

$$E_{Fi} - E_F = kT \ln\left(\frac{N_a}{n_i}\right)$$

$$V_{p0} = \frac{ea^2 N_d}{2\varepsilon_r \varepsilon_0}$$

$$V_p = V_{bi} - V_{p0}$$

$$x_n = \left[\frac{2\varepsilon_r \varepsilon_0 V_{bi}}{e}\left(\frac{N_a}{N_d}\right)\left(\frac{1}{N_a + N_d}\right)\right]^{\frac{1}{2}}$$

$$x_p = \left[\frac{2\varepsilon_r \varepsilon_0 V_{bi}}{e}\left(\frac{N_d}{N_a}\right)\left(\frac{1}{N_a + N_d}\right)\right]^{\frac{1}{2}}$$

$$E = -\frac{eN_d x_n}{\varepsilon_r \varepsilon_0} = -\frac{eN_a x_p}{\varepsilon_r \varepsilon_0}$$

$$N_d x_n = N_d x_n$$

$$x_p \approx W \approx \left[\frac{2\varepsilon_r\varepsilon_0(V_{bi}+V_R)}{e}\left(\frac{1}{N_a}\right)\right]^{\frac{1}{2}}$$

$$C' \approx \left[\frac{e\varepsilon N_a}{2(V_{bi}+V_R)}\right]^{\frac{1}{2}}$$

Mass action law $np = n_i^2$

$$\alpha = \frac{J_{nE}}{J_{nE}+J_R+J_{pE}}$$

$$\beta = \frac{\alpha}{1-\alpha}$$

$$\gamma = \frac{J_{nE}}{J_{nE}+J_{pE}}$$

$$\delta = \frac{J_{nE}+J_{pE}}{J_{nE}+J_R+J_{pE}}$$

$$\alpha_T = \frac{J_{nC}}{J_{nE}}$$

$$V_{pO} = \frac{ea^2N_d}{2\varepsilon_r\varepsilon_0}$$

$$V_p = V_{bi} - V_{pO}$$

$$a-h = \left[\frac{2\varepsilon_r\varepsilon_0(V_{bi}+V_{DS}-V_{GS})}{eN_d}\right]^{\frac{1}{2}}$$

$$p_{E0} = \frac{n_i^2}{N_E}$$

$$n_{B0} = \frac{n_i^2}{N_B}$$

$$n_B(0) = n_{B0}\exp\left(\frac{V_{BE}}{V_t}\right)$$

$$p_E(0) = p_{B0}\exp\left(\frac{V_{BE}}{V_t}\right)$$

$$G = \frac{e\mu_n N_d W a}{L}$$

$$V_{DS(Sat)} = V_{p0} - (V_{bi} - V_{p0})$$

$$V_{GS} = \frac{1}{2}V_p$$

$$I_{DS(Sat)} = I_{p1}\left[1-3\left(\frac{V_{bi}-V_{GS}}{V_{p0}}\right)\left(1-\frac{2}{3}\sqrt{\frac{V_{bi}-V_{GS}}{V_{p0}}}\right)\right]$$

$$I_{p1} = \frac{\mu_n (eN_d)^2 W a^3}{6\varepsilon_r \varepsilon_0 L}$$